Report

ZERO WASTE SCOTLAND

Final report

Review: Odour & flavour taints in malting barley and milling wheat

A review of available literature demonstrating the absence of links between the use of recycled soil amendments and flavour / odour taints in barley or wheat

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Zero Waste Scotland is the new programme created by the Scottish Government to support delivery of its Zero Waste Plan.

It will integrate the activities of WRAP Scotland, Waste Aware Scotland, Keep Scotland Tidy, Remade Scotland, Envirowise in Scotland, NISP in Scotland, and some programmes delivered by the Community Recycling Network for Scotland.

Our vision is a world without waste, where resources are used sustainably. Find out more at www.zerowastescotland.org.uk

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Front cover photography: Winter wheat

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Executive summary

Malting barley is widely grown in the UK for ultimate use in the whisky and beer industries. Milling wheats are also widely grown. It is therefore essential to demonstrate that the use of potentially odorous soil amendments such as livestock manures and digestate will not give rise to odour or flavour taints in these crops. The available literature was reviewed, with the following results:

- Many possible sources of taints in the malting barley and milling wheat supply chains were identified, including: storage conditions, quality of steeping water, and weather conditions at time of harvest. Strategies were already in place to minimise risks from these sources.
- There was no evidence of any links between cereal taints and the use as soil amendments such as food wastes, animal manures/slurries, sewage sludges or paper wastes. Likewise there was no evidence of links between cereal taints and the use as soil amendments derived from organic wastes (such as compost and digestate).
- Within the general context of flavour and odour taint hazards for barley and wheat, the overall risks from the use of organic recycled products during primary crop production were thought to be of low significance.
- It should be noted that this report does not examine the potential further barrier to odour transfer offered by the distillation process itself.

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1.0 Introduction

Agriculture is an important sector of the Scottish economy. The vast majority of land in Scotland is under agricultural production and cereals represent the largest cropped-land use. The UK is the third largest cereal producer in the EU after France and Germany. In 2008, more than 12% of the UK cereal area was grown in Scotland, with a total of 454,000 hectares grown and barley comprising the main cereal crop. In 2007, 28% of the UK's barley area was in Scotland. About 35% of Scottish barley goes into malting (and subsequently into whisky or beer production) while the remainder goes for animal feed, seed or to surplus. Wheat is the second cereal crop in Scotland. More than half of the production is used for distilling, about 36% is used for milling and the remainder goes into animal feed, seed or to surplus[1]. Milling wheat in Scotland is mainly used for biscuit making, as due to the climate, Scottish wheat is normally lower in protein than its English counterpart and less suited to bread making.

Rigorous assessment of the quality of the grain is essential for the malting and milling industries. It is their means to ensure that both food safety standards and the requirements of their customers can be met. Depending on the use of the barley or wheat, different specifications will be required, and tests are carried out to monitor different characteristics in the grain. Commonly assessed parameters include moisture content, protein content and quality, impurities (screenings and admixture), physical damage, specific weight, maturity, enzyme activity (associated with grain germination), varietal purity, moulds and flavour or odour taints (Table 1-1 and Table 1-2). Any failure to meet the standards for these parameters could lead to reduced price or rejection of that load by its intended user, impacting on the economic return achieved by the grower. Laboratory analysis is essential to measure certain parameters, like nitrogen content, moisture, etc. However, decisions on taints and musty odours are based on the subjective experience of experts, not analysis, but these are skills that have been used for over a century[2].

Table 1-1 Quality parameters for UK milling wheat (HGCA, NABIM3)

Characteristic	Standards	Buyer's response
Moisture content	≤ 15%	Price deduction or rejection
Specific weight	≤ 76kg/hl for bread	Price deduction or rejection
Screenings and admixture	≤ 2% impurities (weed seeds, earth, etc)	Price deduction
Variety	Specified by miller (≥1grain out of 50 from different variety)	Price deduction or rejection
Protein quality	Specified by miller	Price deduction or rejection
Protein content	Specified by miller	Rejection
Harber Falling number*	≤ 250sec. for bread	Price deduction or rejection for bread making
Grain hardness	Specified by miller	Price deduction or rejection
Damaged grain	Unacceptable	Price deduction or rejection
Mycotoxins	Legal/contractual levels	Price deduction or rejection
Moulds and odours	Unacceptable	Price deduction or rejection

*Measures the gelling properties of flour, which depend on the activity of the enzyme alpha-amylase

[1] NFUS Scotland. *http://www.nfus.org.uk/farming-facts/what-we-produce?ID=170*
[2] *http://www.ukmalt.com/maltindustry/industry.html*
[3] *Home Grown Cereals Authority and the National Association of British and Irish Millers, respectively*

Table 1-2 Quality parameters for UK malting barley (HGCA)

Characteristic	Standards	Buyer's response
Moisture content	Accept ≤19% (maltster will dry further)	Price deduction or rejection
Screenings and admixture	Typically ≤ 2%	Price deduction or rejection
Variety	Specified by maltster	Price deduction or rejection
Viability	≥ 98% germination	Rejection
Protein content	Specified by maltster	Price deduction or rejection
Damaged grain	Unacceptable	Price deduction or rejection
Micotoxins, lead	Legal limits	Rejection
Pesticides	Legal limits, BBPA/BRI[4] list of accepted substances	Rejection
Moulds and odours	Unacceptable	Rejection

Agriculture is the primary market in the UK for organic recycled products generated from source-segregated wastes (composts and biofertilisers – the latter also known as digestates, resulting from the anaerobic digestion of source-segregated biodegradable inputs). In Scotland, during 2008/9 agriculture accepted 55% of the production of quality composts and biofertilisers (Association for Organics Recycling, Survey 2008/9)[5]. Within this sector, cereals and other combinable crops are the main crop type benefiting from compost usage.

The benefits that these products bring to agriculture are increasingly being recognised, as reflected by the continued development of the compost market over recent years. However, there have also been questions from key quality assurance stakeholders about whether there is the potential for substances in recycled biowaste products to be carried over to agricultural soils, be taken up by the crop and result in odour or flavor taints in products such as malt, beer, whisky or bread. The crop and human / animal health aspects of waste recycling have been and continue to be intensely researched and much has been done to characterise any risks from toxic substances or pathogens, and where necessary, strategies to manage them are in place (Déportes *et al*, 1995, Pepper *et al*, 2008, Domingo *et al*, 2009, Marcato-Romain *et al*, 2009). Much work of this nature has also been supported by Zero Waste Scotland and WRAP (Waste & Resources Action Programme), and is reported elsewhere. The focus of this report is a specific exploration of the potential for flavour or odour taints to be caused by the use of compost or biofertiliser in cereal farming.

2.0 Methodology

To conduct the literature search, search terms were established, including synonyms, spelling variations and different combinations of terms. Searching was largely carried out using the Dialog host, which includes not only the principal agricultural databases, but also food-related databases, environmental science, water, pollution, toxicology and general science databases. A number of these databases also index the grey literature. The titles retrieved from these searches were screened, and subsequently, abstracts were downloaded for the relevant items. These abstracts went through a second round of screening where useful papers were selected. Full text was obtained for these items.

In addition to the standardised interrogations of the databases mentioned above, unstructured searches were also carried out on the Meltwater host, Google, Google Scholar, ISIS Web of Science and Medline.

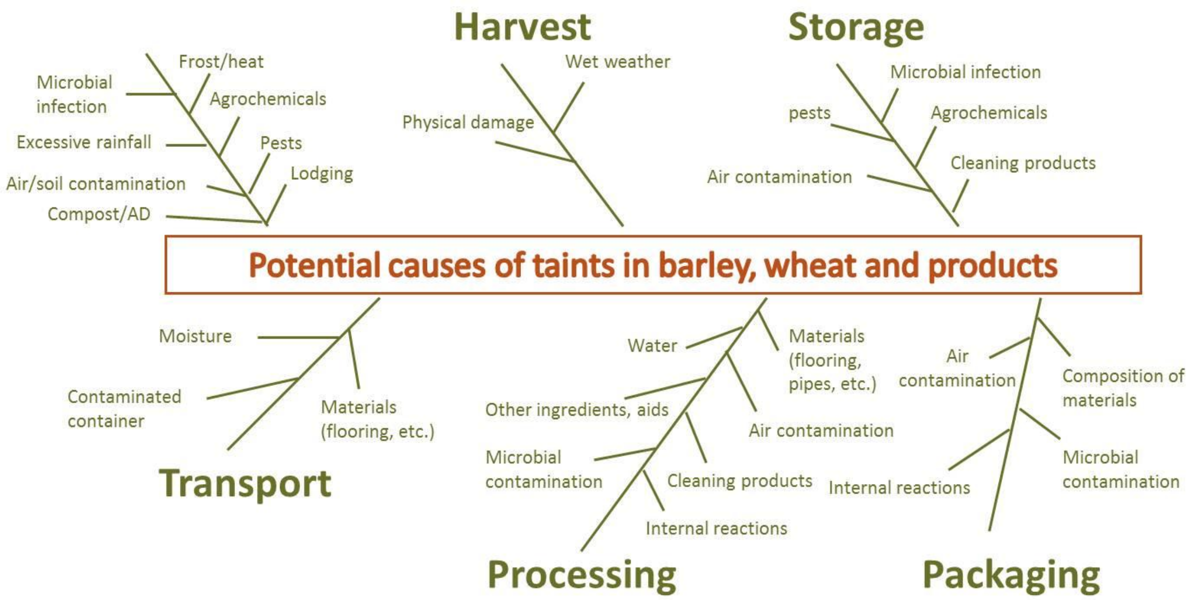
[4] *British Beer and Pub Association/Brewing Research International (http://www.ukmalt.com/documents/TECH-449AGROCHEMSBARLEYFeb11_000.pdf)*
[5] *http://organics-recycling.org.uk/uploads/article1891/Final_AfOR%20annual%20survey.pdf*

3.0 Potential sources of taints in cereals and cereal products

There are many existing sources of potential taints that must be considered in order to understand the general risks of taints in malting barley and milling wheat, and the use of quality compost or biofertilisers must be considered against this background. The terms *taint, off-flavour* and *off-odour* refer to unacceptable flavours (perceived by the senses of taste and smell) or odours (perceived by the sense of smell) in food. The distinction between the terms relates to the source of the unacceptable flavour/odour. Taints result from contamination by foreign chemicals from external sources, whereas off-flavours/odours originate from the chemical reaction of substances naturally occurring in the food, for example, stale flavours in certain foods can be caused by lipid decomposition (Ridgway *et al*, 2010). All stages of the food supply chain have the potential for introduction of such chemicals. Common sources of taints are associated with certain ingredients, microorganisms, processing, packaging and storage.

Many known classes of volatile organic compounds can cause taints in foods and beverages, and usually very small amounts are sufficient. Their detection thresholds are influenced by different factors, such as their chemical structure or the nature of the medium in which they are found. Taste and odour thresholds vary considerably within the human population, which means that food/beverage manufactures must continually monitor their products to prevent even very low levels of tainting compounds from reaching the general public (Saxby, 1993). As mentioned above, within the milling and malting industries, grain is monitored for odours at intake and any load considered tainted will be rejected. According to MAGB[6], for the last five years, around 0.1% of the total tonnage of barley presented to maltsters was rejected due to nose and mould problems (the total percentage of rejection varying between 2.71% and 4.53%). The most common causes of taints in raw cereals are microorganisms or pests associated with grain during growth or subsequent storage prior to delivery to the intended customer. However, other sources of taints exist, not only affecting raw cereals, but also the products of their processing (Figure 3-1).

Figure 3-1 Summary of potential sources of taints along the barley and wheat supply chain



[6] *Maltsters' Association of Great Britain. http://www.ukmalt.com/LABS/rejectionsurveys.asp*

3.1 Potential sources of taints in barley and wheat grains

3.1.1 Moulds and bacteria

Because of their high starch and protein contents, cereals represent an attractive source of nutrients for microbial pathogens. The presence of mould or bacteria in the grain can reduce its storage potential, lead to uneven germination and produce taints or even result in production of mycotoxins, which are unacceptable in almost all end products. Poor growing conditions or improper storage can cause or exacerbate mould or bacterial infection of cereals. Climatic factors, for example rainfall and wind, can exert an important influence on disease epidemics during crop growth (Doohan *et al.*, 2003; Osborne and Stein, 2007). Excessive moisture and high temperature during storage will also favour the proliferation of contaminating microorganisms. A diversity of factors can influence the humidity of the grain during storage, including weather conditions during harvest or loading, moisture in containers and condensation due to drastic temperature changes during loading or to direct contact of cargo with container walls/doors (AFGC, 2007). Correct storage of grain is a priority to ensure harvest quality remains intact, therefore grain temperature and moisture should be regularly monitored (HGCA, Best Practice in grain storage)[7].

During the growth of bacteria and fungi (moulds) many different volatile compounds are produced, such as alcohols, aldehydes, ketones, short chain fatty acids, terpenes, phenols, amines and others. Many of these substances will produce undesirable odours/flavours at certain concentrations. A range of different odours produced in cereals by microorganisms and their responsible volatile compounds have been described (Eriksson *et al*, 1992, Harris *et al.* 1986, Wasowicz *et al.*, 1988, Whitfield, 2003).

Cereals can be infected by microorganisms during growth or during storage. Some of the most common field and storage contaminating species and the taints/compounds that they produce are described below.

- Fungi (Eriksson *et al.*, 1992). The most common field fungi affecting cereals include species of *Alternaria, Cladosporium* and *Fusarium. Alternaria* and *Cladosporium* have been described to produce musty and fungal odours and *Fusarium* produces mostly musty but also fungal, earthy and mashy odours.
- Frequent storage fungal infections in grain are caused by species of *Aspergillus* and *Penicillium*. Many of these species have been associated with musty odours. Some *Penicillium* species produce geosmin or 2-methylisoborneol, compounds responsible for earthy-musty taints (Karahadian*et al.*, 1985, Jelen *et al.*, 2003). Additional odours have been detected from other species, such as fruity (*A. candidus*), and putrid odours (*A. candidus, A. flavus, P. parasiticus, P. raistricki*). Tuma *et al.* (1989) identified odour volatiles associated with microorganisms in damp bin-stored bulk wheat. They reported the production of 3-methyl-1-butanol (provides a burnt flavour) by *Penicillium*, *Aspergillus* and *Fusarium*, which varied depending on the humidity and ventilation conditions. They also found a correlation between the presence of *Penicillium* and the production of 1-octen-3-ol, which provides a musty flavour (Kilcast, 1996).
- Bacteria. Bacteria constitute 90-99% of the microflora found on or in freshly harvested grain (Eriksson, 1992). Under improper storage conditions (eg. high moisture), bacteria may become a factor in producing taints in the grain (Seitz and Sauer, 1992, Tuma *et al*, 1989). Actinomycetes produce both geosmin and 2-methylisoborneol (Schöller *et al*, 2002), causing earthy-musty taints. A strong sour odour has been shown to be caused by *Bacillus subtilis* in barley and wheat (Abramson *et al*, 1983; Eriksson *et al*, 1992). Species of *Pseudomonas* are also common in cereals; they can produce sour, milky, malty or granary odours in grain (Eriksson *et al*, 1992). Tuma *et al.* (1989) found that bacterial species isolated from bin-stored wheat produced 3-methyl-1-butanol as a major odour volatile. They also showed that ventilation of bin-stored wheat had a favourable effect, interrupting the natural progression of microflora and subsequent production of odour volatile compounds.

[7] *http://www.hgca.com/document.aspx?fn=load&media_id=5494&publicationId=4160*

3.1.2 Insects and mites

Some insects and mites are specialised storage pests and do not infest field crops. It is generally known that, in addition to damaging the grain, insects and mites can cause off-odours in grains. Pheromones and other metabolites of grain storage insects and mites have been associated with unpleasant odours in cereals (Seitz and Sauer, 1992; Tuma *et al.*, 1990). Beetles and moths are very common and they tend to invade from previous harvest residues. Removing residual pests by cleaning and cooling stored grain to prevent breeding will help to control infestations. Mites may carry fungal spores and bacteria, increasing the risks of grain contamination.

3.1.3 Agrochemicals

Herbicides, insecticides, plant growth regulators and fungicides are used on cereals in order to achieve high yields and good quality grain. There are taint risks associated with the use of agrochemicals. Laboratory studies have been published describing the fate of some of the chemicals used on barley. Malathion used to treat growing barley was found to be lost during the early stages of processing and none could be detected in the final distilled spirit (Thomas, 1987). Navarro *et al.* (2007) studied the fate of the herbicides pendimethalin and trifluralin, the insecticides fenotrothion and malathion, and the fungicides nuarimol, myclobutanil and propiconazol during the malting process using barley samples spiked in the laboratory. They concluded that residues of water-soluble pesticides on barley tend to be eliminated mainly during steeping (52%), followed by germination (25%) and kilning (23%). No significant decrease was observed during malt storage. Conversely, hydrophobic residues (pendimethalin and trifluralin) remained in the steeped grain, and the authors suggested that they might be carried over to the final product and care must be taken to ensure that these residues do not represent a health risk. Pendimethalin is a herbicide accepted by UK maltsters for use on barley (BBPA/BRI[8], see below). Its permitted maximum residue level (MRL) is 0.05mg/kg. The use of the herbicide trifluralin on barley and wheat is permitted (CRD[9]), although is not included on the list of agrochemicals accepted by UK maltsters. The MRL for trifluralin on wheat is 0.1mg/kg. Inoue *et al.* (2011) investigated the fate of 368 pesticides spiked into malt during beer brewing and concluded that the vast majority of them were eliminated, with 312 pesticides not detected at all in beer or detected at trace levels, and only nine pesticides remaining in the beer at >60% of their input concentration. Only two of those nine pesticides are included in the BBPA/BRI list of allowed pesticides, namely imazaquin (MRL 0.05mg/kg) and imidacloprid (MRL 0.1mg/kg). However, none of these studies dwell on the potential for these pesticide residues to cause taints.

Pesticides have been reported to cause taints in other crops. Trichloroanisole (TCA), a potent musty flavour compound, was found in potatoes that had been rejected by consumers in Canada. The taint originated due to unusually high temperatures during the growing season in a soil that had been treated with gamma-cyclohexane hexachloride to control wireworm (Daniels-Lake *et al*, 2007). In another instance, an off-odour was detected in melons that had been treated with profenofos and the responsible chemical (4-bromo-2-chlorophenol) was shown to be a product of profenofos degradation (Sanchez Saez *et al.*, 1991).

No reports of agrochemical-originated flavour or odour taints in cereals have been identified during this review.

The use of agrochemicals is closely monitored and assurance schemes are in place in order to minimise their use and the levels of residues remaining in crops. Flour millers only purchase crops from growers who participate in farm assurance schemes, meaning that they are subject to independent inspection to check that they are using these products correctly[10]). The Scottish Quality Cereals (SQC) assurance scheme[11] was formed in 1994 and its members now account for 90% of Scottish combinable produce. Membership of SQC ensures members meet the requirements of the Food Safety Act, 1990 – which covers compliance with agrochemical residue limits.

[8] *http://www.ukmalt.com/documents/TECH-449AGROCHEMSBARLEYFeb11_000.pdf*
[9] *https://secure.pesticides.gov.uk/pestreg/*
[10] *See www.nabim.org.uk*
[11] *www.sfqc.co.uk/farm/sqc.asp*

Within the UK malting industry, BRI (Brewing Research International) and BBPA (British Beer and Pubs Association) publish a list of agrochemicals accepted for application to malting barley and wheat used for malting and brewing. They aim to test agrochemicals which, because of their chemical nature or timing of application to barley, could potentially affect either the malting, brewing or fermentation processes, or could cause undesirable taints in the finished beer. The European Directive 93/71/EEC (Annex III) establishes that before placing plant protection products on the market, among other assessments, tests to evaluate the potential occurrence of taints and odours in food crops must be performed when the risk is suspected or when a similar active ingredient has already been shown to cause taint. The possible occurrence of adverse effects on transformation processes, such as brewing and malting, or on the quality of their products must also be assessed. In order for a chemical to be included in the list of accepted chemicals, BRI performs an initial assessment of factors including chemical nature, mode of action, time of application and available test data. Following this initial assessment, BRI will conduct additional malting or brewing trials designed to test the suitability of treated crops for processing specifically within the malting and brewing industry (MAGB, 2011).

The tight regulations and adherence of the industry to assurance schemes would suggest that the risks of taints in Scottish barley and wheat from direct use of agrochemicals are low.

3.1.4 Grain integrity

The malting process is a controlled germination of the barley during which each corn produces enzymes that break down seed proteins, carbohydrates, and other reserves. It is critical that this process (malt modification) occurs in a balanced and uniform manner. Uneven germination will result in brewing and distilling problems, including off-flavours. UK Maltsters have therefore set a minimum standard for germinative energy of 98% for barley to attain before it goes to steep[12]. Skinned or broken barley corns can lead to uneven germination, as the husk regulates water uptake and protects the shoot from breakage during germination. Moreover, damaged corns are more prone to fungal attacks during storage or malting, increasing the risk of fungal taints. Damage to barley or wheat grain can be due to handling or environmental factors (eg. heat or frost damage)[13].

3.1.5 Airborne contaminants

Airborne contamination is a frequent cause of direct tainting, both of growing crops and during processing and packaging. Air diffusion within warehouses or transit containers contaminated by other commodities often results in tainting (Baigrie, 2000). Taints can occur due to the transfer of volatile substances from cleaning products, disinfectants, wood treatment products, etc. It is also possible for compounds from different sources to react when they come into contact and produce a new potential taint. For example, new polymer flooring, contaminated with traces of phenol, can react with chlorine-based disinfectants to produce chlorophenols. If chlorine-based disinfectants are used on the same site as phenolic disinfectants then a reaction can occur, not only in the drain but also potentially in the atmosphere (Olieman, 2003; Mottram, 1998; Ridgway *et al.*, 2010).

Crops can also be contaminated by substances from nearby industrial/urban activity. Airborne benzene has been shown to accumulate in some fruits and other crops (Collins *et al*, 2000), while plants grown at an urban roadside were shown to accumulate volatile organic compounds such as toluene (Keymeulen *et al*, 1995).

3.1.6 Soil contaminants

Soils can be polluted by a range of different point or diffuse sources, such as accidental spills of industrial wastes or atmospheric deposition. Although many soil contaminants are extensively degraded by naturally occurring biological and chemical processes, it is possible that certain compounds remaining in soil might pose a taint hazard if taken-up by the crops of interest. Schroll *et al.* (1994) studied the uptake pathways of organic chemicals from soil by agricultural plants. They observed not just root but also foliar uptake of hexachlorobenze by barley and oats, of the herbicide chlorotoluron by winter wheat and of the herbicide trichloroacetic acid by barley and oats. They also observed translocation of the herbicides from root to leaves and *vice versa*. This would suggest that if

[12] *www.ukmalt.com*
[13] *www.ambainc.org*

volatile compounds with taint potential are present in the soil, they may be taken up by the plant, either through the roots or through volatilisation and leave uptake, and possibly migrate to other tissues and cause taints. Agrochemicals, as explained earlier, go through taint tests before they are placed on the market, but other contaminating chemicals in the soil may pose less-manageable risks.

3.2 Potential sources of taints in barley and wheat products

Any point in the food chain offers an opportunity for taints to occur. Even when the raw barley or wheat grain is free from undesirable flavours/odours, care must be taken to avoid sources of contamination during the processing and packaging stages, such as those discussed here.

3.2.1 Water

Water is a raw material used in the processing of barley and wheat. Any taints affecting the water supply have the potential to be transferred to the end product. Species of potentially taint-causing *Streptomyces*, *Nocardia*, *Micromonospora*, *Microbispora*, *Oscillatoria* and *Phormidium* can contaminate water. These microorganisms produce the compounds geosmin and 2-methylisoborneol, which are common causes of musty-earthy odours in water supplies (Saxby, 1996; Suffet *et al*., 1993). Contaminated water is a known source of must-earthy malodourants in beer, for example (McGarrity *et al*., 2003).

Other common water-borne taints are caused by phenolic compounds, particularly chlorophenols. These can be formed by spontaneous reaction of phenol with the free chlorine present in mains water. Plastic fittings and hoses or phenol-based resins used as protective coatings on processing plants often function as ready sources of phenol (Baigrie, 2000; Brocca *et al*., 2002). Trichloroanisole formation can easily occur in water distribution systems and it is linked mainly to fungal contamination (Piriou *et al*., 2001).

3.2.2 Other raw materials

Other raw materials (ingredients) and processing aids can become contaminated with microorganisms or chemical substances that may cause taints. Bacterial or fungal contamination of malt and wort can easily occur, generating musty, fungal and other flavours. It has been shown that bacterially-produced butyric acid (rancid, sickly flavour) in beer adjunct (an additional source of fermentable sugars used in brewing) passes almost entirely through the brewing process into the final product (Bennett, 1996 and references therein). Wild yeast of the genus *Dekkera/Brettanomyces*, although desirable for some beers, can cause mousey off-flavours in others. It can also cause a plastic flavour during fermentation[14].

Ingredients used during processing of barley and wheat can become tainted through various routes. Bromophenol can migrate from packaging material (recycled paper, cardboard, fireproofing materials) into the ingredients and cause an inky flavour. Chlorinated phenols can also come from packaging materials and produce a mouthwash taint[8].

Naturally occurring chemicals in non-contaminated ingredients can also give rise to taints. For example, S-methylmethionine, formed during germination of barley, is converted to dimethylsulphide (DMS) during kilning. The kilning regime influences the amount of DMS produced, which if excessive, will cause an undesirable flavour (Bennett, 1996).

3.2.3 Processing

Control of the different processing steps is important in order to prevent the formation of undesirable flavours. Kilning, as seen above, can influence the occurrence of off-flavours. High temperature processes like wort boiling or baking generate many compounds through the Maillard reaction. Some of these compounds contribute to desirable flavours and aromas, but others can

[14] *www.flavoractive.com*

cause off-flavours. For example, free fatty acids in flour can give rise to Maillard-type browning compounds with unpleasant flavours during kilning (Becker, R).

Sulphur compounds are important sources of off-flavours in whisky and beer (although small concentrations in beer contribute positively to the flavour). Factors such as yeast strain, fermentation conditions, metal ion concentration and sources of sulphur determine the amount of sulphur in the final product (Lee *et al.*, 2001).

Many other steps in the processing of barley and wheat (storage of ingredients, cleaning practices, composition of any materials in contact with the products) have the potential for introduction of taints and off-flavours and therefore, need to be properly controlled. Whitfield (1986) reported a case of taint in flour where the water in a storage tank became contaminated with phenols from the breakdown of the bonding resin of the fibreglass lining, which subsequently reacted with hypochlorite used to clean the processing equipment, ultimately resulting in chlorophenol in the processing lines and contamination of the flour.

3.2.4 Packaging

Different materials used in packaging may generate taints. For example, the inside of the aluminium kegs used for beer is coated with a lacquer that, if insufficiently cured, may cause phenolic taints. A sulphur taint may develop if the lacquer on the inside of aluminium cans is damaged, and the same situation in steel cans will result in a metallic taint due to migration of iron from the can into the beer (Bennett, 1996).

The colour of the glass of beer bottles can also have a significant impact on the flavour of the beer. Brown glass offers the highest protection against lightstruck/sunstruck off-flavour, which is caused by a light-induced reaction between different compounds in beer (Bennett, 1996).

Defective wooden casks used for whisky maturation can become contaminated with fungi or actinomycetes, tainting the spirit with mouldy/earthy notes (Lee *et al.*, 2001).

Paper, cardboard and plastic packaging can be sources of taints derived from residual monomers, additives, and printing inks. The concentration of taint compounds can increase in storage due to microbial action and oxidation reactions. Chloroanisoles are derived from the action of microorganisms on chlorophenols used industrially as fungicides and biocides in wood and fibreboard, and contaminate food through packaging or stacking on treated wooden pallets (Ridgway *et al*.., 2010).

3.2.5 Transportation and storage

Bottled beer has been reported to have been tainted by ingress of trichloroanisoles through the bottle closure. In one instance the source of the taint was mouldy fibreboard within shipping containers; in a separate instance the source was mould growth on shrink-wrapped pallets (McGarrity *et al*.., 2003).

In addition to microbial residues in shipping and storage containers, residual cleaning products can also cause taints such as alkaline flavours from caustic soda and fishy flavours from quaternary ammonium compounds (Bennett, 1996).

3.3 Impact of agronomic conditions and practices on taint risks

Agronomic conditions and practices can influence the risks of taints. Some aspects of cereal production in Scotland that may play a role in the causes of taints in malting barley and milling wheat are discussed here.

3.3.1 Climate

More than 90% of the cereal production in Scotland is concentrated in the east of the country. Temperature and rainfall in this region tend not to be extreme but nonetheless, the success of agriculture depends on the weather. Temperatures below -15°C are rare, but late frosts in spring are common and can damage the grain during early growth. Damaged grain is more susceptible to infections from fungi, which are one of the main causes of taints in cereals. In terms of rainfall, the harvest months of August and September can be very wet. As the grain moisture reaches equilibrium with the atmosphere at maturity, it is normally too wet when harvested to store without artificial drying (Hay *et al.*, 2000). This is extremely important, as high moisture content encourages fungal infection during storage. Wet weather at harvest can also induce early sprouting, having a detrimental effect on quality, for example, of malting barley, which should germinate evenly and rapidly during malting. Uneven germination can cause off-flavour in the final product.

3.3.2 Soil and irrigation

The texture, structure and drainage properties of soils all influence the amount of water that they retain. Soils that are excessively wet may contribute to disease development. Some soils have a low available water capacity and sometimes need irrigation, especially when rainfall is low. The majority of water used for irrigation is abstracted directly from rivers or underground aquifers. Additionally, some surface waters are stored in on-farm reservoirs to provide continuity of supply during the summer. These waters used for irrigation can be polluted by point source pollution (e.g. from septic tank effluent, spillages or leaks, landfill leachate, etc) or by diffuse pollution (e.g. from application of organic or inorganic fertilisers or pesticides to land) (FSA, 2009; SEPA, 2009), therefore having the potential to contaminate crops with chemicals that might cause taints. Even though irrigation of cereals is not usually needed in Scotland, residual contamination may be present in the soil from irrigation of a different crop grown previously in the same ground.

3.3.3 Agrochemicals

The use of herbicides and pesticides is necessary in order to manage weeds, pests and diseases in crops. Equally, farmers use plant growth regulators to shorten plant stems and thereby reduce their susceptibility to lodging i.e. being flattened by wind and rain. Lodged crops can have lower yield, lower quality, require more drying, are more susceptible to grain infections and are more difficult to harvest than standing crops[15].

Factors like cropping patterns, varieties, husbandry, rotation, cultivation, pesticide use and probably also climatic changes have an effect on the incidence of pests and diseases and also on the evolution of populations of weeds, pests and pathogenic species over time (SAC , 2007; Hay *et al.*, 2000). As discussed earlier, these contaminating species can potentially cause taints in cereals, as can the chemicals used to manage them. Therefore, a combination of adequate use of agrochemicals and good farming practices that help to minimise weeds, pests and diseases is necessary.

[15] *www.food.gov.uk/multimedia/pdfs/pestresidcropcereal.pdf*

3.4 Management of taint risks within the UK cereal industry

The evaluation of taints and off-flavours in wheat and barley is a subjective exercise based on the skills and judgment of experts, not on analytical tests. There are not specific risk assessments for taints, however, the presence of taints is closely linked to crop quality and to factors like microbial contamination, growing, harvest, storage conditions and hygiene, all of which are covered by quality assurance schemes followed by the industry.

UK maltsters and millers only source their grain from assured farms. Assurance schemes like the Red Tractor's Assured Combinable Crops and Sugar Beet Scheme or Scottish Quality Crops, provide assurance of good standards on farming, supported by independent inspections. The standards set out by these schemes cover a whole range of factors that may influence food safety and quality, including practices that have an impact on the risk of taints, such as use of agrochemicals, hygiene, grain storage conditions, safe storage of chemicals, etc. The HGCA (Home Grown Cereals Authority) also provides a Grain Storage Guide and a Safe Storage Time Calculator, which helps farmers to manage aspects like humidity, pests, duration of storage, etc.

Climatic and cultivation conditions have an impact on taints and also on crop safety. They are considered, for example, in the risk assessment for mycotoxins, where factors like cultivation, variety, fungicides, rainfall at flowering and rainfall at harvest are taken into account.

The food safety control system complies with the Codex Alimentarius Food Hygiene requirements[16], which helps to identify and control hazards during production and processing. This, together with the relevant quality assurance schemes, aids the management of safety and taint hazards during processing.

3.5 Compost and biofertiliser

Biodegradable wastes, including food wastes, garden wastes, cardboards and others, can be segregated at source – for example, by households – and then collected separately as a discrete biodegradable feedstock for processing through composting or anaerobic digestion. This feedstock can be transformed into several valuable commodities, such as compost, biogas and biofertiliser (anaerobic digestate). These methods of processing waste allow valuable organic matter and crop nutrients to be returned safely to agricultural soils. In Scotland an average of 36.7% of local authority collected municipal waste was recycled/composted during 2009/10, amounting to more than 1,173,000 tonnes (SEPA).

Composting is a microbiologically mediated process through which the readily degradable organic material in organic wastes is degraded and stabilised in the presence of oxygen. Compost can be derived from different types of waste including food scraps, garden prunings, untreated wood by-products, animal manures, crop residues, biodegradable packaging, and some other materials (Kuo, 2004; ADAS, 2008). During the process, the organic nitrogen (N), primarily as proteins prior to composting, is broken down to more readily usable forms of nitrogen which are then re-synthesised into other forms of organic N in microbial biomass and humic substances (organic matter). The organic matter in compost is key for soil fertility. It is a reservoir of nutrients, from which inorganic nitrogen (available for plant uptake) is only slowly released. It also provides other nutrients like phosphorus, potassium, sulphur, magnesium and trace elements. Compost is typically used as a soil amendment to enhance the chemical, physical and biological properties of soil. Amongst the benefits provided by compost are reduced need for fertilisers, increased soil water holding capacity, reduced nutrient leaching and better soil structure and water movement. Some composts have the ability to suppress fungal diseases (Yogev *et al*.., 2006, Saadi *et al*.., 2010).

Anaerobic digestion is a process where putrescible plant and animal material (biomass) is converted into useful products by microorganisms in the absence of oxygen. Biomass is put inside sealed tanks and (either in parallel within a single digestion vessel, or in a series of separate vessels) naturally occurring microorganisms break down the biomass in discrete stages, ultimately releasing biogas. Biogas comprises a mix of methane and carbon dioxide that represents a source of clean renewable energy. The material left over at the end of the digestion process is rich in nutrients (nitrogen, phosphate and potassium) and is an excellent

[16] *CAC/RCP 1-1969, Rev. 4-2003. Recommended international code of practice general principles of food hygiene.*

replacement for mineral fertilisers. This material is known as biofertiliser or anaerobic digestate[17]. Almost any biomass can be processed in an anaerobic digester; including food waste, crop residues, biosolids (sewage sludge), slurry and manure. However, it should be noted that, at the time of writing, biosolids are not a permitted input for either composting or anaerobic digestion processes intended to comply with Scottish end-of-waste specifications (including the PAS100 and PAS110 specifications for product quality). Further information on this is given below.

Risks associated with spreading materials derived from recycled wastes on to land are low, primarily due to low concentrations of contaminants that they might contain that could present a risk to human and animal health, or to the environment (Davis and Rudd, 1999; Gendebien *et al.*, 2001). Excessive nutrient overloading, excessive concentrations of heavy metals or organic contaminants, and pathogens are possible hazards (Amlinger *et al.*, 2004). In order to protect humans, animals and the environment from these potential hazards, the use of waste-derived products such as compost and biofertiliser needs to be properly managed.

Compost and biofertiliser complying with relevant SEPA requirements[18] are 'likely to be' considered non-wastes in Scotland, although derived from waste inputs. Part of these requirements include third-party accreditation to the UK's PAS100 (compost) or PAS110 (biofertiliser) specifications. Each of these Publicly Available Specifications includes quality requirements for process input materials, guidance over minimum processing parameters and lists of quality checks that must be passed by the materials for them to be deemed compliant. Due to the relatively restricted nature of the inputs allowed by these specifications (source-segregated biodegradable wastes[19] or in the case of biofertiliser, source-segregated biodegradables wastes and/or biodegradable wastes that have been completely removed from any non-biodegradable packaging prior to processing) and the integrity of the recycling processes, relatively few parameters need to be checked in the final products. Quality check parameters for both specifications include material stability, limits on non-biodegradable contaminants and limits on potentially toxic elements (such as copper and zinc) and heavy metals (such as lead and cadmium). Other types of compost or biofertiliser may also be used on agricultural land in Scotland, but such uses generally remain within the framework of waste management controls, whilst the materials are not processed within or tested to the quality requirements of the PAS schemes.

3.6 Types of materials accepted for composting and anaerobic digestion

As mentioned above, many different types of biodegradable waste can be recycled through composting and anaerobic digestion. In Scotland, the only acceptable waste inputs for compost and biofertiliser to be spread to agricultural land are those that are source-segregated. Non-wastes such as purpose-grown crops or livestock manures are also permitted inputs for compost or biofertiliser intended to be spread to agricultural land.

According to the results from a survey carried out by the Association for Organics Recycling (Survey of the UK Organics Recycling Industry 2008/9), over 75% of the biodegadable waste recycled in the UK in 2008/09 was garden waste from civic amenity/bring sites and kerbside collection, 8% was from kerbside (household) co-collections[20] of garden and food wastes, and 1% was from kerbside (household) collections of separate food waste. Other classes of input materials (provided they meet the requirements of PAS 100 or PAS 110) include:

- Food/beverage industry wastes
- Farmyard manures/slurries
- Untreated wood, paper, cardboard, leather, fur, textile, biodegradable packaging
- The fate of the different constituents of waste during processing is an important matter, as it will determine the quality of the recycled product, its suitability for the intended use, and the potential for any hazards to be present at unacceptable levels.

[17] *www.biogas-info.co.uk*
[18] http://www.sepa.org.uk/waste/waste_regulation/idoc.ashx?docid=7406c869-8f0b-45ee-8a5e-94ce825953f9&version=-1
[19] *Source-segregated biodegradable materials are those that are stored separately from, collected separately from and not subsequently combined with any non-biodegradable or harmful materials*
[20] *Where biodegradable garden wastes and biodegradable food wastes are collected together in the same container*

The survey by the Association for Organics Recycling indicated that less than 1% of source-segregated waste was subjected to anaerobic digestion, the rest being treated by different methods of composting. Numbers of anaerobic digestion facilities are expected to increase significantly in the near future, and the market for biofertiliser is anticipated to grow in parallel with this.

3.7 Potential of food and garden waste as a source of taints

In principle, microbial activity or chemical composition of compost and biofertiliser could be sources of volatile compounds that might possibly taint crops if they survive long enough in the soil environment and are present in suitable forms for crop uptake and accumulation. However, no evidence has been found in the literature of taints in crops originating from the use of recycled organic (biodegradable) soil amendments. Some studies focus on the effects of organic farming on produce quality, but data on taints are scarce. Nevertheless, it is worth considering potential sources of volatile substances in recycled organic soil amendments that could taint crops such as malting barley and milling wheat. In green and food wastes, which currently constitute the majority of the biodegradable waste recycled into soil amendment products in the UK, microbial activity and chemical contamination would be the main factors to consider as possible sources of taints.

3.7.1 Microorganisms

During the microbial degradation of organic matter in biodegradable wastes, various volatile organic compounds are produced, including aliphatic and aromatic hydrocarbons, chlorinated compounds, organic acids and sulphur-containing compounds (Kuo *et al.*, 2004). These compounds are responsible for the unpleasant odours emitted during poorly managed composting processes, and different strategies can be applied to reduce these emissions. However, in mature compost those volatile compounds will almost all have been eliminated and therefore are not available for uptake by the plant. Eitzer (1995) described that most of the volatile organic compounds in aerobic composting plants are volatilised during the preliminary stages of the process, i.e. in the tipping floors where the wastes are discharged, in the shredder, and in the initial active composting phase where the temperatures reach thermophilic levels (45-70^{o}C). A decreasing concentration of almost all VOCs was observed from fresh to partially composted material and to cured compost. Komilis *et al.* (2004) found that VOCs emissions during composting of the organic fraction of municipal solid (mixed) wastes decreased during the thermophilic phase of composting.

This review did not find evidence of compost causing taints in cereal crops.

Odorous compounds like volatile fatty acids (VFAs), sulphur compounds, toluene, ethylbenzene, styrene, p-cresol, indole, and skatole are also produced during anaerobic digestion and some may accumulate in any dewatered solid fraction. Sulphur compounds decrease upon several day’s storage, whereas indole, p-cresol, skatole and others can persist for longer periods (Webster *et al.*, 2006; Higgins *et al.*, 2008). Aerobic stabilisation of the digestate fiber has been shown to provide additional stabilisation of organics and rapid elimination of phytotoxic compounds like ammonia and VFAs, with sulphur compounds requiring a few extra days to be reduced (Drennan *et al.*, 2010). Several pre- and post-digestion treatments exist that help the chemical stabilization of the digestate.

This review did not find evidence of biofertiliser causing taints in cereal crops. (Please see further discussion below on the similar absence of such evidence for digested sewage sludges and other common soil amendments such as poultry litter and livestock slurries).

3.7.2 Contaminating chemicals

Chemical contaminants that are present in feedstocks can potentially still be found at low levels in the final output of recycling processes (WRAP, 2009a). Contaminants may enter composting feedstocks from a variety of diffuse sources. However, composting has been shown to promote chemical decontamination, and laboratory experiments showed that some pesticides and herbicides are totally degraded during the process (Lemmon and Pylypiw, 1992; Déportes *et al.*, 1995). Furthermore, the PAS 100 mandates that an audit trail be maintained by compost producers throughout the composting process and that samples of compost routinely be tested at accredited laboratories for contaminants and for phytotoxicity through a plant bioassay.

This review did not identify any evidence of chemical contaminants present in compost or biofertiliser being taken up by crops to cause taints.

3.8 Potential taint risks from other feedstock materials used for composting and AD

Although the majority of the organic soil amendment products currently used in agriculture in Scotland are composts derived from green waste, other types of materials are accepted as feedstock and they may also be potential sources of taints. It was therefore considered valuable to briefly review these potential risks in this report. It should be noted that a number of the input materials can also be spread to agricultural land directly without treatment[21]. Further discussion of potential taints from such practices is presented in a subsequent section of this report.

3.8.1 Food/beverage industry

Wastes from the food and drink industry are by nature free of contaminants (Davis and Rudd, 1999). The main potential source of volatile contaminants from the food/drink industry would be wastewater from washing and cleaning processes, which frequently contain detergents, bleach or disinfectants. Some of these chemicals or their derivatives may have the potential to cause taints if not fully eliminated during the anaerobic digestion process. As mentioned earlier, the biological treatment of wastewaters can eliminate chemical contamination, sometimes very efficiently. Alkylbenzene sulfonate, an anionic surfactant widely used in cleaning products, was shown to be greatly eliminated from industrial wastewater by anaerobic digestion when present at concentrations ≤ 500mg/l. Higher concentrations of the chemical in the wastewater would require additional treatment (Hosseini and Borghei, 2005).

Certain foodstuffs, such as onions, leeks and others, contain potent odorous substances, which might lead to concerns about using large amounts of these materials, for example from food manufacturer's waste, for recycling into soil amendments. However, no evidence has been identified during this review of taints originating from the use of this type of waste materials in compost or biofertiliser.

3.8.2 Farmyard manure/slurry/poultry litter

A number of volatile gasses contribute to the odour of livestock manures/slurries. These include ammonia, hydrogen sulphide and other sulphur-containing compounds, volatile fatty acids, and other more pungent compounds such as indoles, phenols, para-cresol, and skatole. The main concerns regarding these gasses relate to the nuisance caused by their unpleasant odours. Farmyard wastes may also contain contaminating substances like detergents (for example, from washing-down in dairy units), residual veterinary medicines or agrochemicals (Kuepper, 2003). Appropriate treatment of these wastes should ensure that the levels of these substances are minimal in the recycled soil products.

3.8.3 Textiles, leather, packaging

Tribromophenols and their derivatives are used as fire-retardant agents as well as general fungicides for use with leather, textiles, plastics, paper and pulp. A range of volatile organic compounds are known to be present in waste from paper processing. Methods for bleaching fabric or degreasing animal skin for leather production can generate organohalogenated compounds in the sludge. Chorophenols can also be present in leather and other materials like newspapers. (AFGC. 2007, Bellamy *et al.*, 1995, Trépanier *et al.*, 1998, Tandy *et al.*, 2008).

[21] *http://www.sepa.org.uk/waste/waste_regulation/application_forms/exempt_activities/paragraph_7.aspx*

3.9 Potential taint risks from other materials directly applied to land

Although quality compost and digestate are increasingly used by farmers and growers, a range of other materials is used directly in agriculture, and it was considered valuable to include in this report information about possible taint hazards within those materials. As it is the case for compost and biofertiliser, the use of other types of materials on land is regulated by legislation in order to manage any possible health or environmental risks[21].

A range of materials are commonly applied to agricultural land, and Table 4-1 illustrates the relative volumes of these.

Table 3-1 Quantities of materials applied to agricultural land (Brian Chambers, pers comm). The category 'Other wastes' includes food wastes, whilst 'biosolids' are treated sewage sludges

Type	**Fresh weight**	**Dry weight**
	(*million tonnes*)	
Livestock manures[1]	90	16
Biosolids[2]	3-4	1.1
Compost[3]	1.3	0.8
Paper crumble[4]	0.7	0.3
Digestate[3]	0.1	~
Other 'wastes'[5]	6-7	~

[1] Williams *et al.,* 1999. ; [2] Mat Davis, Environment Agency (*Pers Comm*) & Scottish Water, 2008. ; [3] WRAP, 2009b; [4] Gibbs *et al.,* 2005; [5] WRc, 2009.

3.9.1 Food waste

Food waste is normally expected to be free of contaminating chemicals. Risks of taints from food waste spread to land are thought to be low, unless poor management practices are used. Food can sometimes be spoiled by internal chemical reactions that produce off-flavours, like lipid oxidation in fatty foods produces a rancid off-flavour (Hamilton, 2003). If large volumes of spoiled/tainted food were to be spread on to agricultural land at one single time, the high concentration of the offensive compounds might be a taint risk for the growing plant. This, however, is not thought to represent a high risk.

3.9.2 Sewage sludge

Organic compounds, such as pharmaceuticals, fragrances, surfactants, and ingredients in household cleaning products are likely to be found in sewage sludge (Eriksson *et al.* 2008). Some of these substances are known to cause taints in certain circumstances; for example, cleaning products are common sources of food taints in processing lines.

For environmental and health reasons, the use of sewage sludge in agriculture is tightly regulated and treatment of the sludge is required before it can be spread on to land. Sewage sludge is often treated by anaerobic digestion, during which a large proportion of the contaminating chemicals are degraded (degradation rate depending on type of compound) and most of the volatile compounds present or generated as result of biological action are volatilised during the process. (Komilis *et al*.., 2004; Carballa *et al*.., 2006).

Various aspects of sludge application to land have received much attention, including its effect on soil properties, plant yields and chemical accumulation by crop plants. However, very few studies focus on the impact of sewage sludge on crop quality, especially flavour. Vecchio *et al*.. (1984) examined the quality of two varieties of tomatoes grown in soil amended with municipal sewage sludge and reported that the sludge-grown tomatoes had less flavour than the control and their overall quality was rated lower. However, control and sludge-grown tomatoes were rated similarly in off-flavour and off-odour. Reference is made in their paper to two other studies involving sweet corn, carrots, string beans and peas grown in sludge-amended soil. Sludge-grown sweet corn and peas were found to taste better than controls, whereas sludge-grown carrots had a sharp undesirable after-taste. No difference was observed between the taste of control and sludge-grown string beans.

This review did not find evidence of sewage-sludge causing taints in cereal crops.

3.9.3 Paper waste

Sludges and crumble from paper treatment are permitted materials for spreading on land, as long as they contain no ink. A number of potential taint-causing chemicals are used in the paper industry, including solvents and chlorine compounds used to bleach and delignify pulp. Residues of these compounds, such as chlorophenols, can be present in the product as well as in the waste and could potentially be sources of taints (Mottram, 1998). However, this investigation has not found any documented cases of taints in any crops caused by paper waste materials applied to land.

3.9.4 Farmyard manure/ slurry / poultry litter

Livestock manure, slurries and litters are the inevitable result of animal production activities, with solid manures comprising a mix of excreta and bedding (normally cereal straw, wood shavings and sawdust), and liquid manures (i.e. slurry) composed of a mixture of excreta and waste water from farming activities (SORP, 2003). These types of material contain nutrients that are beneficial in agriculture, but they can also contain residues of contaminating substances like veterinary medicines, pesticides and cleaning agents used in the facilities (Kuepper, 2003). Some of these chemicals might potentially cause taints. Also, some volatile organic compounds that occur naturally in animal faeces (eg. skatole, indole, phenol compounds) have a strong odour and could potentially impart taints if taken up by the plant. However, as with the other types of soil amendment discussed, data on the impact of farmyard manures, slurries and poultry litters on crop flavour are very limited. Thybo *et al*.. (2001) examined the effects of different organic growing conditions on the quality of cooked potatoes. They found that potatoes manured with cattle slurry had slightly higher off-flavours and off-odours as compared to those grown with cattle manure, but the difference was extremely small and the levels of off-flavour and off-odour were qualified as "low level", although flavour/odour data for conventionally grown potatoes was not reported. No correlation was made with any particular compound. Sankar *et al*.. (2009) reported that yellow onions grown with a combination of poultry and farmyard manures had better flavour and texture than their inorganically fertilised counterparts.

4.0 Discussion

Taints and off-flavours in milling wheat and malting barley can be caused by many different compounds, originating from many different sources at various points during primary and secondary crop production. The highest risks of taints in grains derive from microbial infection (bacteria, moulds) or from insect or mite infestation of the grains themselves. Cereals can be attacked by these organisms during growth or during storage, and different factors such as local climate, specific weather conditions or agronomic practices, influence the likely occurrence of diseases or pests. In Scotland, for example, the frequently wet conditions during harvest are an aggravating factor that needs to be carefully considered. These are well known hazards, affecting not only taints, but also toxicity, yield and general quality of the cereals, and well defined management strategies exist.
There are other sources of taints and many points in the cereal supply chain where taints and off-flavours are known to occur. Many of the responsible compounds and their origin are well documented. Some of these sources of taints are common to other food/beverage products and some are specific to the processing of malting barley or milling wheat. Mechanisms are in place to manage risks, although occasionally taint incidents do still occur.

In addition to the well-known sources of taints in wheat and barley, this review highlights other possible risks of taints such as contaminants in the air, soil or irrigation water. A key aim of this review was to understand whether or not there is evidence that the use of compost and biofertiliser on agricultural land has been linked to flavour or odour taints in cereal crops. The addition of soil amendment products to land, naturally, changes the chemical composition of the soil, and it is reasonable to suppose that certain foreign chemicals might be taken up by the growing plant and possibly cause taints. Use of biowaste-derived products is very beneficial for agriculture because of their fertilising and soil conditioning properties, but if poorly managed it can also be a route for undesirable substances to reach the soil. A wide range of organic waste materials can also be applied to land directly without treatment, but often organic waste is subjected to stabilisation processes like composting or anaerobic digestion.

Research on chemical residues in soil as sources of taints is scarce. Some studies have shown that organic compounds present in the soil can be taken up by wheat and barley through the roots, or they can sometimes migrate to the atmosphere (volatilise) around the plant and be absorbed through the leaves. However, no evidence has been found in the literature of organic volatile compounds being taken up from the soil by wheat or barley and causing taints in the cereal crop.

Even though the use of organic soil amendments in agriculture is increasing, this review has not identified reported incidents of taints imparted by compost or biofertiliser. This suggests that the risks of this happening are low. It is known that appropriate composting and anaerobic digestion protocols provide very good biological and chemical stabilisation of waste material, and many potential taint-causing chemicals are eliminated during processing. This would also suggest that processing organic waste through composting or anaerobic digestion would be advantageous over less intensive processing methods or straight spreading to land, as compounds carrying risk of taint, as well as potential pathogens or toxic substances, can be eliminated through processing. Moreover, good practice would dictate incorporation of either compost or biofertiliser in soil ahead of crop establishment. This leaves a window of some weeks before the plant reaches a stage where it is filling the grain – and even more time before final harvest – minimising exposure of the grain to any possible volatilisation from the applied materials and allowing extra time for soil stabilisation of potential residual compounds. Also, compost and biofertiliser can only be applied at relatively low rates (between 30-40 tonnes per hectare, depending on total N content). This would seem to make it even less likely that there could be undesirable accumulation of tainting compounds.

There are studies in the literature investigating the effect of different types of organic soil amendments on the quality of different crops. Although no specific information on taints has been found, some of those studies report results of sensory tests (better taste, no difference, less flavour). The results vary, depending on the plant, type of soil, type of waste used as amendment, etc. It is difficult to predict if certain chemicals in the waste will survive the digestion or composting process, if they will be available for uptake by the plant and whether or not they will ultimately cause taints. Whilst the lack of scientific evidence or investigation suggests that the risks from such taints are low, concerns may remain amongst specific grower or farmer groups. In this case, specifically designed experiments would be required to address the specific concerns and provide the necessary data. Information on factors such as survival of particular compounds through the composting/anaerobic digestion process, degradation into different risk compounds and uptake/accumulation in the plant would be needed to provide the required empirical evidence. Input materials worthy of particular investigation would be those containing high concentrations of potent odorous compounds such as ammonia, hydrogen sulphide, skatole (present in animal faeces and urine), chlorophenols, solvents or chlorine compounds (present in paper industry waste). Of course, even if compounds of interest survive composting or anaerobic digestion and are then absorbed by crops of interest, there is no certainty that they would survive processing of the harvested crop to cause a taint in the final product.

5.0 Conclusions

- There are numerous possible sources of taints in the malting barley and milling wheat supply chains, and strategies are already in place to minimise risks.
- Based on the literature investigated during this review, the risks of taints being caused by the use of compost and biofertiliser are thought to be low. Moreover, the management strategies that are in place to control potential health and environmental risks in biowaste-derived products (input restrictions, waste segregation, quality protocols) also help to mitigate potential taint risks.
- Within the general context of flavour and odour taint hazards for barley and wheat, the overall risks from the use of organic recycled products during primary crop production in Scotland are thought to be of low significance.
- The literature explored during this review does not provide evidence of any links between cereal taints and the use as soil amendments of organic waste materials (food, animal manures/slurries, sewage sludge or paper waste) or products derived from organic waste (compost and biofertiliser).
- If full risk assessment were required (to examine the fate of specific compounds that might be present at high concentrations in certain types of waste) then primary research would be required, as the necessary data do not currently appear to be available in peer-reviewed scientific literature.

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